MATHCAD Based Printed Microwave LPF Simulation Package

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Abstract- **A simulation package for a printed microwave low pass filter (LPF) based on the powerful mathematical solver MathCAD Premium 2000 has been developed. The chosen structure of the LPF is the stepped-impedance type. The developed package is mainly intended for student usage in the Microwave Laboratory of Universiti Teknologi Malaysia. However, assignments for the Microwave subject can also be given to undergraduate students. Challenging assignments may be given to the Masters students for their Microwave/RF subject. The development of such educational design and simulation package helps the university in saving large amount of costs for buying laboratory experimental set-ups.**

Keywords:
Printed low pass filter, simulation package, microwave.

I. INTRODUCTION

This paper presents the development of a simulation package based on a powerful mathematical solver available at the Advanced Microwave Laboratory, Faculty of Electrical Engineering, Universiti Teknologi Malaysia. The solver; MathCAD Premium 2000 [1], can be incorporated with texts and users are also able to view and work interactively within the created file or package. Graphics are available for any graphical representation in the form of two and three dimensional figures. The development of such simulation software is highly needed since commercial simulation softwares are expensive. The designed package can be used for assisting undergraduate students of Microwave courses being taught at this faculty through laboratory assignments or case studies using computer simulations. More challenging assignments can be developed for the postgraduate level. The selected microwave structure for this project is the low pass filter. Microwave filters in the form of printed structures offer attractive alternative to lumped elements especially at higher frequencies. Printed structures of several number of sections occupy less amount of space compared to the corresponding lumped element structures. The lengthy design formulations for several basic low pass configurations are readily available in the literature. The formulations allow the frequency response to be computed. Presentation in the form of attenuation or insertion loss versus frequency can be easily displayed.

II. LPF DESIGN PRINCIPLES

The chosen LPF structure is the stepped impedance type of cascaded sections of alternate low- and high-impedance microstrip lines [2]-[5]. This is a distributed structure which can be derived through the conversion of lumped inductor (L) and capacitor (C) elements. The network topology of a three element LPF and its corresponding distributed structure are depicted in figures 1(a) and (b), respectively. The input and output characteristic impedances are 50 ohms. The three sections of the

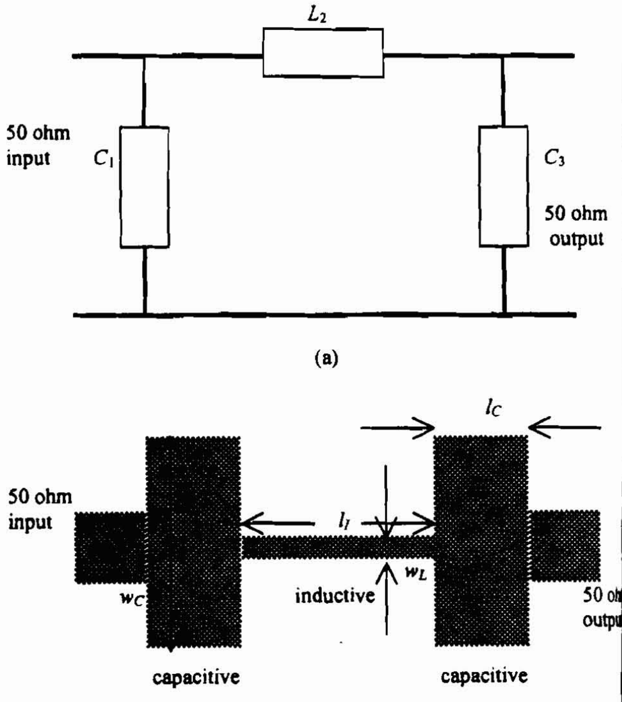

Figure 1. A three element LPF structure (a) network topology (b) corresponding distributed configuration.

corresponding distributed configuration are made up of lengths and widths determined using specific formulations available in the literature.

The desired response characteristic chosen as an example is the Chebyshev or also known as the equal ripple response as depicted in figure 2. The cut-off frequency, f_c, occurs at the 3 dB attenuation reference level. Ripple occurs in the pass band region. The roll-off rate in the transition band is sharp. The ultimate attenuation of the stop band begins at the stop band frequency, f_s.

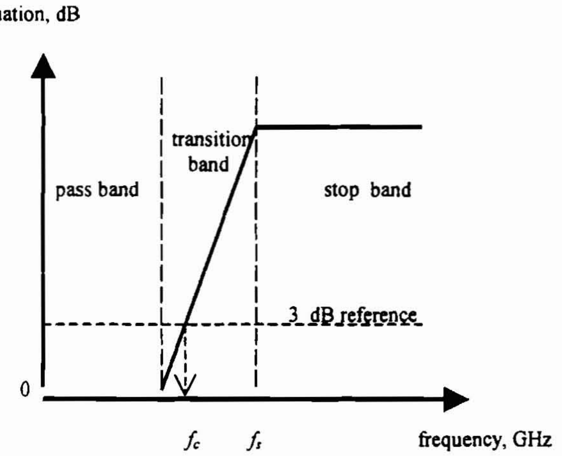

Figure 2. Chebyshev response characteristic: attenuation (dB) vs freq.

The attenuation can be obtained using the formulation

$$A = 10\log\left[1 + (10^{\frac{R}{10}} - 1)(C_n^2(\tfrac{f}{f_c}))\right] \text{ dB} \qquad (1)$$

where R is the ripple, n is the order of the filter and C_n is the Chebyshev polynomial for the nth order. C_n is given by

$$C_n(\tfrac{f}{f_c}) = 2(\tfrac{f}{f_c})C_{n-1}(\tfrac{f}{f_c}) - C_{n-2}(\tfrac{f}{f_c}) \qquad (2)$$

where

$$C_0(\tfrac{f}{f_c}) = 1,\ \ C_1(\tfrac{f}{f_c}) = \tfrac{f}{f_c} \ \text{ and } \ C_n(1) = 1.$$

For example, the first, third and fifth order of the Chebyshev response can be represented by the attenuation given by the following formulations, respectively;

$$A = 10\log\left[1 + (10^{\frac{R}{10}} - 1)((\tfrac{f}{f_c})^2)\right] \qquad (3)$$

$$A = 10\log\left[1 + (10^{\frac{R}{10}} - 1)(4(\tfrac{f}{f_c})^3 - 3(\tfrac{f}{f_c})^2)\right] \qquad (4)$$

$$A = 10\log\left[1 + (10^{\frac{R}{10}} - 1)(16(\tfrac{f}{f_c})^5 - 20(\tfrac{f}{f_c})^3 + 5(\tfrac{f}{f_c})^2)\right] \qquad (5)$$

However, the optimum order can be computed as

$$n = \frac{\cosh^{-1}\sqrt{\left[\dfrac{10^{\frac{A_s}{10}} - 1}{10^{\frac{A}{10}} - 1}\right]}}{\cosh^{-1}(\frac{f_s}{f_c})} \qquad (6)$$

where A_s is the ultimate attenuation at the stop band frequency.

The inductive and capacitive component values of the filter are first designed from the prototype elements. Transformation into distributed elements of corresponding widths and lengths are then performed. The chosen microwave laminate in this project is the TLC laminate with the following specifications; relative permittivity = 2.75, thickness of substrate = 0.368 mm, thickness of copper clad = 0.035 mm, conductivity of copper clad = 5.882 x 10^7 S/m and surface roughness = 0.0024.

The proposed filter is designed with the following specifications;

Cut-off frequency = 2.75 GHz
Stop band frequency = 3.75 GHz
Attenuation at stop band frequency = 30 dB
Ripple = 0.01 dB

The capacitive and inductive line impedances of the outmost elements are found to be 24 and 90 ohm, respectively. The input and output impedances are to be matched to 50 ohm lines.

III. SIMULATION USING MATHCAD

The attenuation formulation of equation (1) can also be written as

$$10\log[1 + j\cosh(n\cosh^{-1}(\tfrac{f_s}{f_c}))^2] \qquad (7)$$

Solving n using MathCAD is very simple. It has the symbolic function which let users specify any parameter in the formulation to become the subject. In this case, the value of optimum n is easily obtained by making n the subject of the symbolic function to be solved. This results in two forms of n;

$$\frac{\cosh^{-1}\left[\frac{1}{j}\sqrt{j\left(\exp\left(\frac{1}{10}A_s \ln 10\right)-1\right)}\right]}{\cosh^{-1}\left(\frac{f_s}{f_c}\right)} \tag{8}$$

and

$$\frac{\cosh^{-1}\left[-\frac{1}{j}\sqrt{j\left(\exp\left(\frac{1}{10}A_s \ln 10\right)-1\right)}\right]}{\cosh^{-1}\left(\frac{f_s}{f_c}\right)} \tag{9}$$

However, only the first solution is valid for computation of n since this yields positive value. Formulations (8) and (6) are indeed identical.

IV. COMMERCIAL NUMERICAL SIMULATION

Two commercially available numerical simulation softwares are used to simulate the performance of the designed dimensions of the low pass filter. These are the simple PUFF [6] software and the more expensive Serenade Design Environment™ software by Ansoft Corporation. Filters of increasing number of orders or filter elements are designed and simulated. The optimum number of order determined using MathCAD yields n equals to 9. Results computed from both PUFF and Serenade are in good agreement with each other. Figures 3 to 6 showed the circuit layout for the designed three, five, seven and nine element lumped component filters and the corresponding distributed configuration, respectively, using Serenade. The designed dimensions are input into PUFF and simulation is performed. The results are illustrated in figures 7 to 10 for the four filters, respectively.

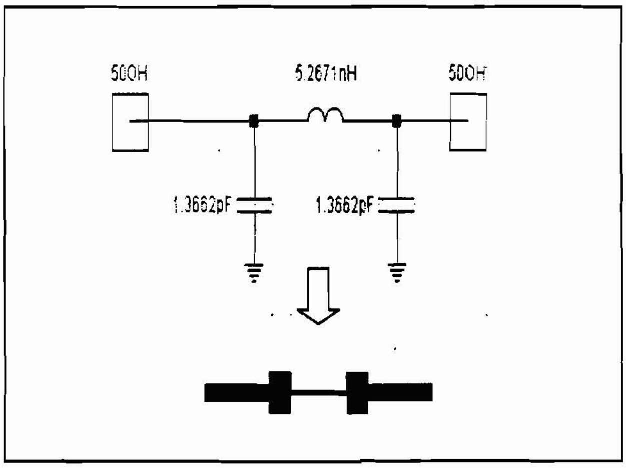

Figure 3. Designed three element filter and the corresponding microstrip configuration.

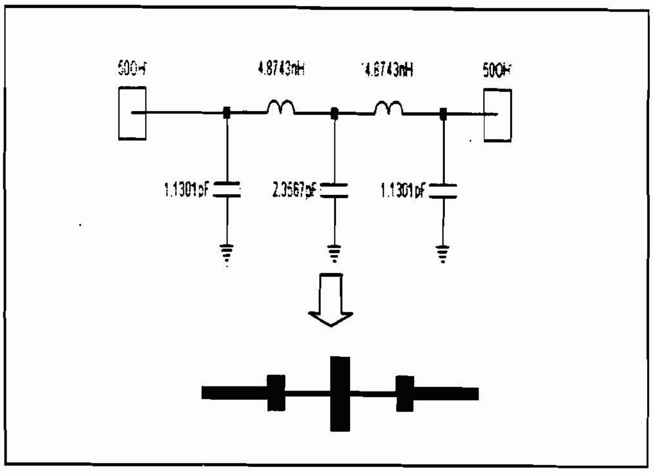

Figure 4. Designed five element filter and the corresponding microstrip configuration.

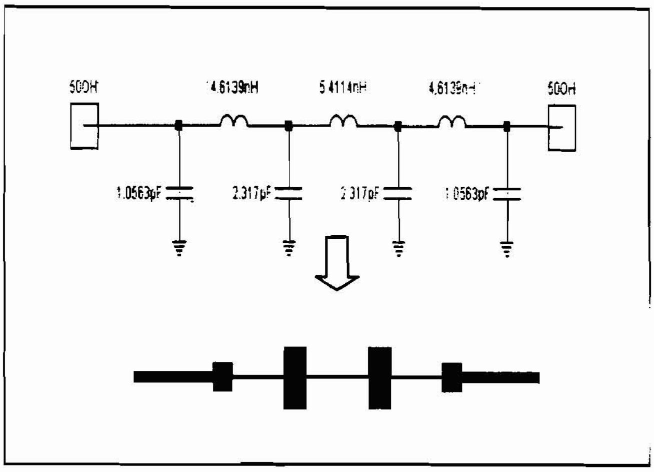

Figure 5. Designed seven element filter and the corresponding microstrip configuration.

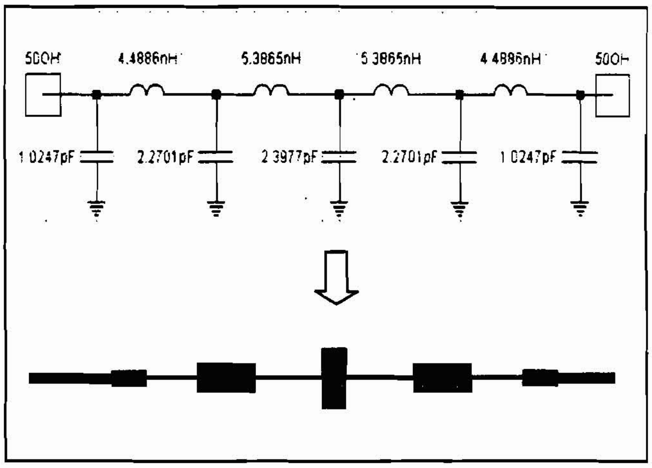

Figure 6. Designed nine element filter and the corresponding microstrip configuration.

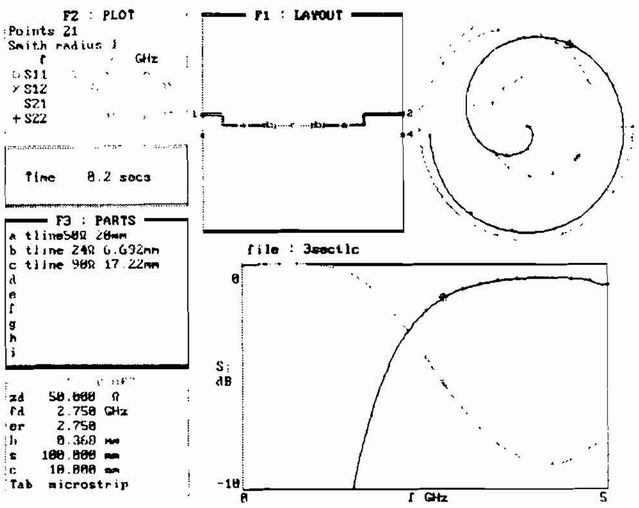

Figure 7. Designed three element filter and the PUFF simulation responses.

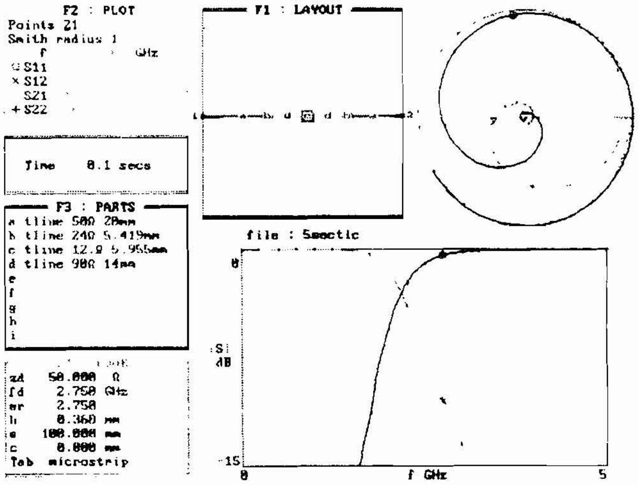

Figure 8. Designed five element filter and the PUFF simulation responses.

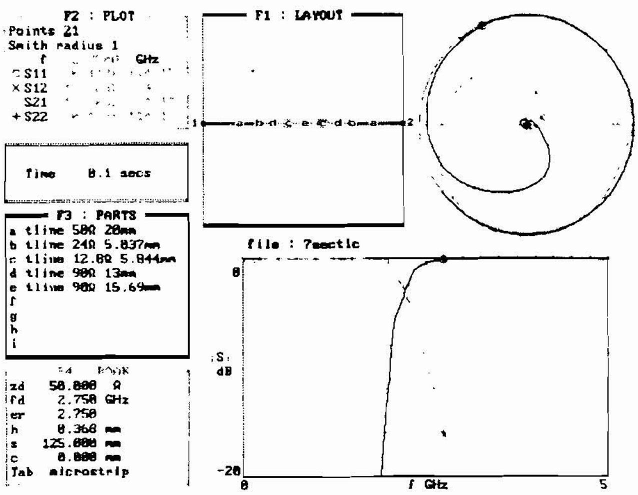

Figure 9. Designed seven element filter and the PUFF simulation responses.

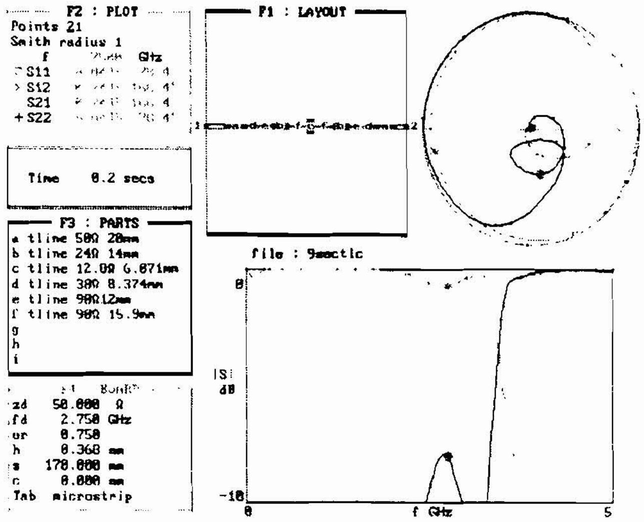

Figure 10. Designed nine element filter and the PUFF simulation responses.

The inverse of attenuation, insertion loss, is computed from both PUFF and Serenade. This is shown in the form of scattering parameter, S_{12}. In addition, the input and output return losses, S_{11} and S_{22}, respectively, can also be observed. The return loss responses have not been obtained using MathCAD since the corresponding formulations have not been derived.

Simulation results obtained using Serenade are illustrated in figures 11 to 14 for the four filters, respectively.

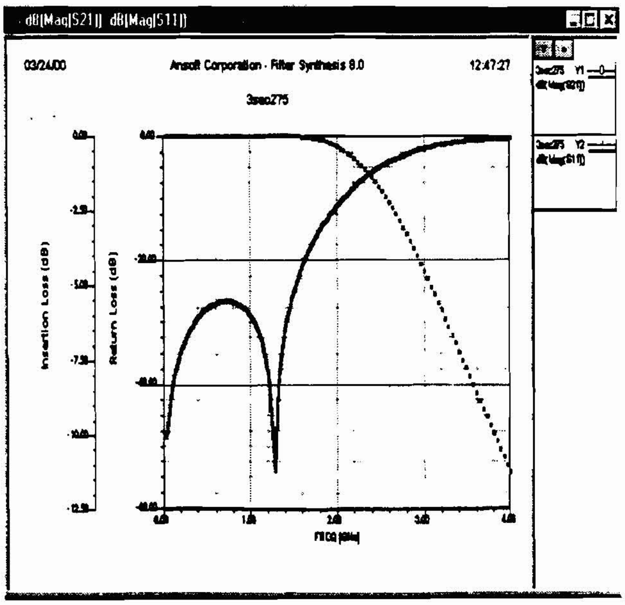

Figure 11. Serenade responses for the three element filter.

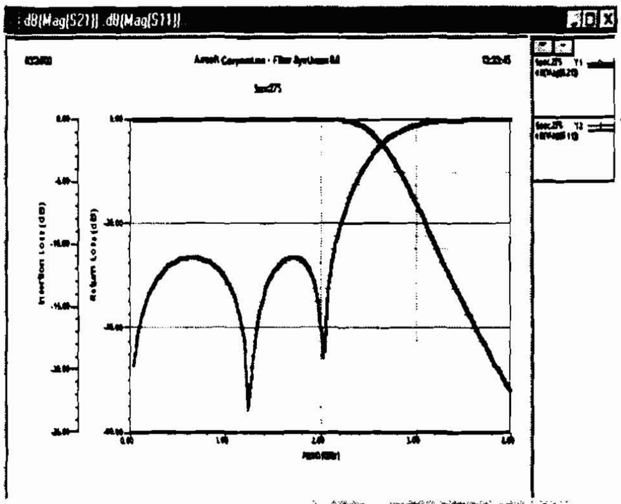

Figure 12. Serenade responses for the five element filter.

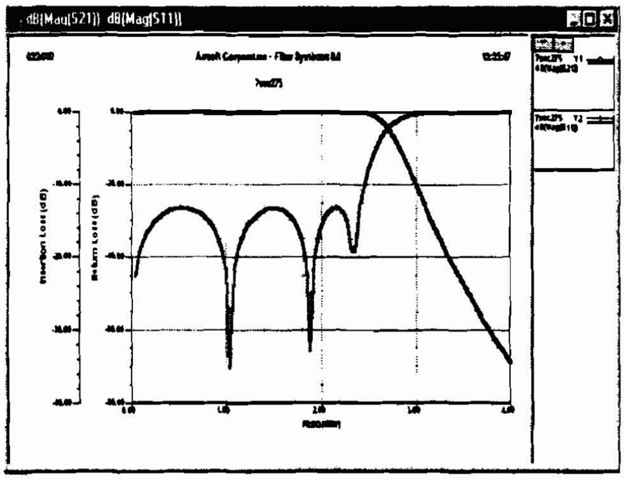

Figure 13. Serenade responses for the seven element filter.

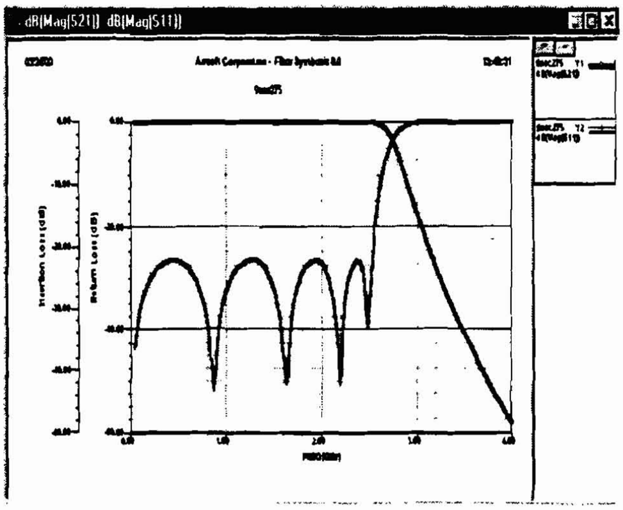

Figure 14. Serenade responses for the nine element filter.

V. CONCLUSION AND FURTHER DEVELOPMENTS

The design of the printed low pass filter has been eased with the powerful mathematical solver MathCAD Premium 2000. Attenuation characteristic and the corresponding insertion loss response can be computed from the design formulations available. Optimum order of the designed filter and hence the optimum number of filter elements can also be quickly computed. Comparisons with available commercial numerical simulation softwares showed good agreements. Work is currently under way in integrating the MathCAD simulation with a Microsoft Visual C++ 6.0 based LPF design software. Calculations from both softwares agree well with each other.

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